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COST EFFECTIVE HIGH-SPEED MACHINE VISION WITHIN THE INDUSTRY OF PRESERVED VEGETABLES

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Abstract: The paper describes a sophisticated and low cost Automated Visual Inspection System (AVIS) for quality control of preserved orange segments, widely applicable to production processes of preserved fruits and vegetables. Main constraints concerning these kind of inspection applications are addressed: the need of on-line operation together with an strong requirement of economic profitability. The strong commitment of above circumstances have forced the development of a flexible and low cost AVIS architecture. An special effort has been put in the design of the defect detection algorithms to reach two main objectives: accurate feature extraction and on-line capabilities, both considering robustness and low processing time. An on-line implementation to inspect up to ten orange segments by second is reported.

Keywords: Industry automation, Computer vision, Pattern generation, Software specification.

1. INTRODUCTION

Along the last years more and more applications arise for visual inspection of many different products with on-line achievement [Jain, 1995][Jyrkinen, 1999][Kjaergaard, 1999]. This has been possible mainly due to the arrival of more powerful tools (hardware and software) into the vision developers community at better prices. These applications have not yet massively reached -although partial solutions have been reported, like fruit sorting- the fruit/vegetable processing industry due to several reasons: complexity of the inspection task, traditional idiosyncrasy within the manufacturers and market particularities for this kind of production. Production workshops are highly automated (raw fruit classification, washing, peeling, separation into different sizes, packaging…) being the inspection task the only one that is still performed by skilled operators, which represents the 30% of the man power in a typical workshop. Inspection mistakes and variability, cost to the Spanish producers of preserved fruit/vegetables 10 Meuro per year (aprox. 5% of 50.000 Tm produced every year).

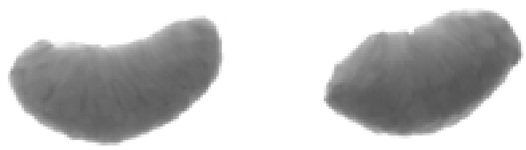
Standards as Quality Standards for Preserved Vegetables Exportation or Quality Standards for Preserved Vegetables, among others, set commercial categories for preserved orange segments according to maximum percentage of broken slices and peeling defects. The challenge is to improve present manual classification by means of an automated system which assures on-line adaptation to production conditions.

2. SPECIFICATIONS FOR THE VISUAL INSPECTION TASK

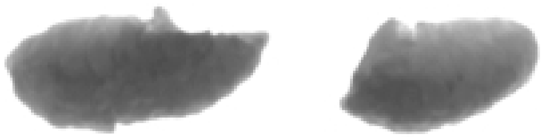
Illustr. 1. Human inspection.

As shown in illustration 1 the process of visual inspection at each workshop where preserved vegetables/fruits are prepared is made at the final stage, after the vegetables/fruits have been peeled and separated into pieces. In our case study – preserved orange segments- this inspection is achieved by four to six expert operators placed along both sides of a conveyor belt which carries the segments with a typical speed of 2 m/min with a global inspection rate of about ten segments by second.

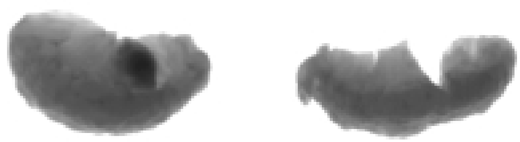
Illustration 2 show images from orange segments with different quality. There are different product qualities; final quality corresponds to a maximum content of broken segments. No strange elements are permitted (such as peels, leaves, ...), neither are the so called double segments.



a) Good segments



b) Broken segments



c) Bad segments

Illustr. 2. Orange segments.

The automated visual inspection demands:

1-High inspection rate: up to 10 orange segments by second.
2-High performance qualities: quality certification must be higher than the reached by human inspectors.
3-High flexibility adapted to on-line change of inspection criteria: it is necessary to easily change inspection parameters for updating actual product quality.
4-Compactness: the system must permit to include itself within the production line in an easy and fast way.

3. ARCHITECTURE FOR THE AVI SYSTEM

To achieve the above mentioned requirements, the developed AVI System is formed up by:

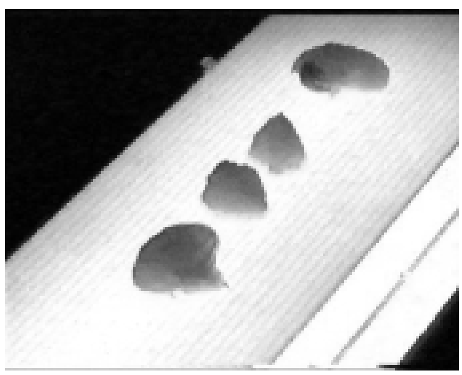
Mechanical supporting System (MSS). Its aim is to align orange segments as they come from size selectors and move them at controlled speed under the camera. The MSS also assures separation among segments. Main components are the align and centering device, the speed-controlled conveyor belt and the selector module. This last component lets segments pass through the packing units or to reject them to different circuits: scrap, poor quality or double segments. Rejection is provided by means of controlled pressured air jets. Illustrations 3 and 4 show details of the mechanical system.

Control Unit (CU). The mechanical system is driven by the Control Unit. It receives orders from the Master Unit and converts them into signals for the aligning and separating elements. Also transmits to the Master Unit signals coming from different sensors. Finally, it drives the pressured air jets and automatically governs the shooting of cameras.

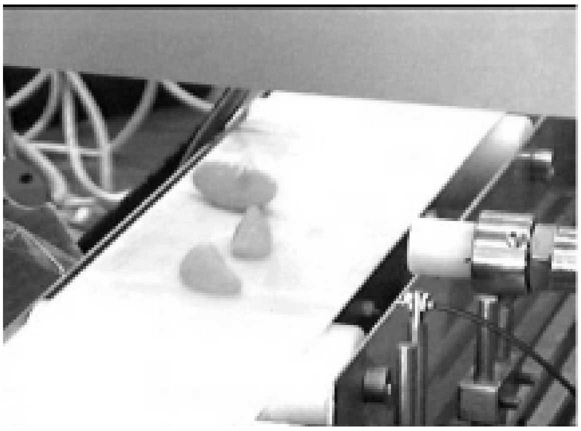
Image Acquisition Unit (IAU). For enhancing the visual properties of the product under inspection it has been set a combination of back and front lighting. Back lighting allows to accurately obtain the shape, while front lighting, in combination with color filters, allow an easy segmentation of scrap materials mixed with the segments. The inspection unit contains a CCD progressive scan camera with programmable shutter mounted on a six-freedom-degree head that allows a perfect fitness and centring. It also incorporates its own stabled double lighting system.

Image processing Unit (IPU). On-line performance of the AVI system is assured by using high performance image processing units based on the powerful multi-processor DSP TI TMS320C80.

Master unit (MU). The overall supervision and intelligence of the AVI system relies on the Master Unit. It is responsible for AVI system interfaces with the Control Unit, the human operator and the production process. The MU generates inspection strategies as a result of inspected product and requirement from the operator. Also, the MU hosts a Quality Assessment System, which seeks for quality evolution and takes corrective actions when necessary.



Illustr. 3. Conveyor belt carrying orange segments.

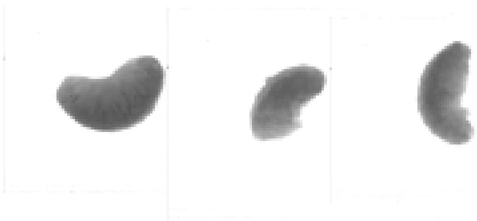


Illustr. 4. Detail of selection area.

4. PREPROCESSING STEPS

To face the described automation the following procedure has been developed:

First, both Control Unit and Master Unit actions over the Mechanical System and image acquisition devices result in an image as the one shown in illustration 5, where segments appear separate and without crossing image borders.



Illustr. 5. Image for processing.

Notice that this image contains only orange segments, since any other object –peels, organic materials, plastic labels,...- has been excluded by using color filters and directly classified as scrap to be adequately removed from the conveyor belt.

The required processing for the automated inspection can be divided into two different steps: color filtering [Miller, 1996] and bi-level image processing.

Color analysis supplies slice surface information, which allows the detection of defects like peel pieces, white filaments or presence of strange materials (e.g. labels). All these defects cause the segment to be rejected for canning and must be eliminated before following processing steps. For this purpose a combination of color filters has been arranged that permits immediate segmentation.

The second phase consists on the identification and characterization of each segment to determine their quality. This face is accomplished using a two-level adaptive threshold which allows to extract the shape while isolating inner defects as seeds. After that, different measurements are made using binary images from segments.

5. OBTENTION OF THE FEATURE VECTOR

To identify the quality of every segment, we get a feature vector containing different characteristics which give a measurement of the segment shape.

A. Features based on spatial distribution of segment mass.

After a deep statistical analysis [Baillie, 1997] of different features over a population of more than 500 orange segments, we have selected central moments –order 2 and 3- and the set of seven invariant moments proposed by Hu [Hu, 1962].

Also some others *aspect features* have shown useful, as compactness, ratio perimeter/area, and measurements from the segment inertia matrix:

$$IN = \begin{pmatrix} I_x & 0 \\ 0 & I_y \end{pmatrix}$$

$$\frac{Area^2}{I_x \cdot I_y} \qquad \frac{I_x}{I_x + I_y} \qquad \frac{I_y}{I_x + I_y}$$

B. Associated distribution to segment signature

It has also been used a simple unidimensional representation of the segment perimeter corresponding to the distance from the central mass to perimeter points as a function of clockwise angle [Gonzalez, 1992], as indicated in figure 1.

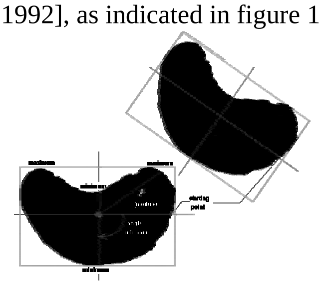


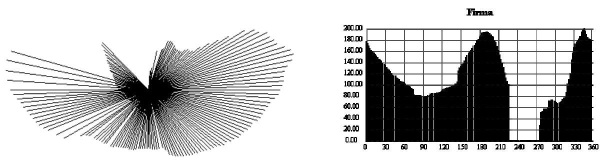
Fig. 1. Signature procurement.

A key point when using this feature –signature- for segment characterization has been a good selection for the starting point. Although promising results where obtained selecting most distant perimeter point from mass center, more robustness was obtained when considering the selection of most distant point situated on the principal axe of the segment. This is due to the way to determine this axe, from the covariance matrix calculated using all perimeter points.

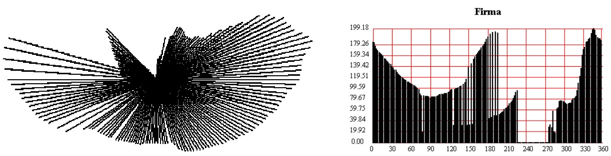
Under the hypothesis of scale uniformity concerning both axes and scanning in successive intervals of angle ϑ, a change in shape produce a corresponding change of signature amplitude. An efficient method to normalize this result consist of scaling all functions in such a way that we always get the same range of values (e.g. [0, 1]), although useless in presence of noise. To solve this drawback, we have implemented a normalization based on the signature standard deviation; for this purpose every sample is divided by the variance, which produces a variable scale factor inversely proportional to size changes, and working very closely to an automatic variance control.

When obtaining the signature two possibilities have been considered: to assign longer or shorter distance in a given direction, that is, considering extern or inner evolving. Better results are obtaining using the inner evolving as it can be observed in figure 2.

a) orange segment



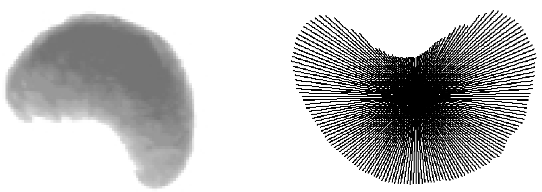
b) inner evolving



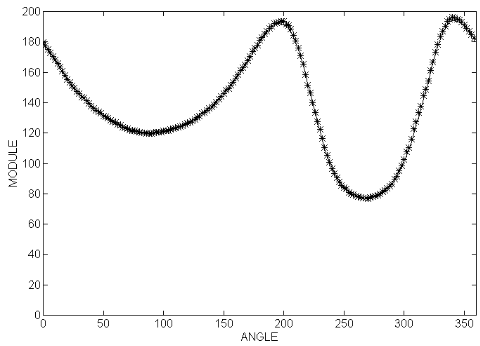
c) extern evolving

Fig. 2. Signature considering extern and inner evolving.

A signature for a typical segment can be seen in figure 3.



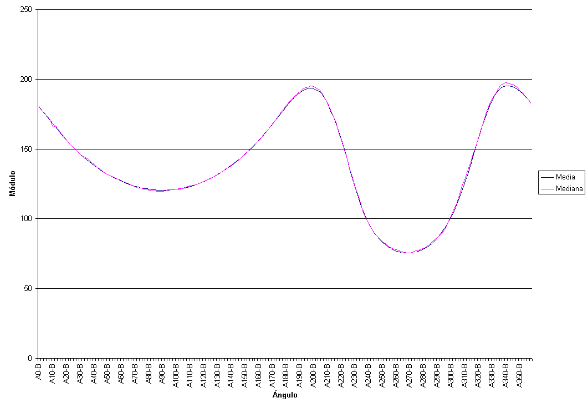
a)



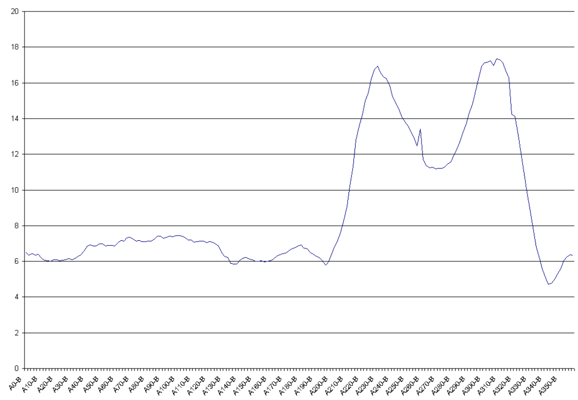
b)

Fig. 3. Signature (b) for a typical good segment (a).

The proof of goodness for this characteristic comes from the distributions for the average value, median and standard deviation, shown in figure 4.



a)



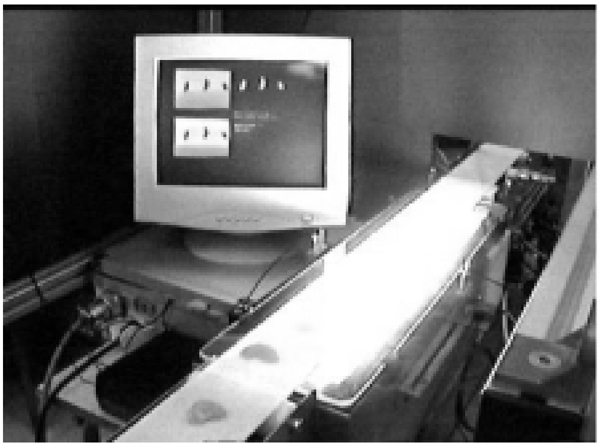
b)

Fig. 4. Average, median (a) and variance (b) values for the signature corresponding to a population of 500 orange segments.

It can be observed an almost perfect fitness between average value and median distributions, which reinforces the hypothesis of normality. Also, from the standard deviation distribution we can deduce that there is an interval where shape randomness becomes more important, thus allowing a better tuning of the discriminant function [Novales, 1998].

6. PROTOTYPE

AVI System is being developed by DSIE Group belonging to the Universidad Politécnica de Cartagena. At present the test bed shown in illustration 6 has been arranged for testing purposes.



Illustr. 6. Prototype.

The designed interface includes a menu driven adjustment of inspection parameters like feature selection, thresholds, quality standard,... with visual feedback. Other parameters like integration time for cameras, light selection,... are automatically set by the system. This feedback allows the inspection supervisor to have on-line information when updating inspection parameters, which has made possible to on-line change the inspection strategy.

7. RESULTS

We have considered a pattern as a collection of data binned in k (k=180) classes forming the desired distribution for the segments. Therefore the inspection process consists on analyzing if the signature obtained is statistically equal to that pattern. Using the theoretical $\chi2$ 0.95 statistic ($\chi2=212$) and passing a $\chi2$ test over a sample of 132 orange segments we obtained a percentage of 14,6% of classifying a good segment like bad (type I error) one and a 10,4% percentage of classifying a bad segment as a good one (type II error) as figure 5 shows.

Observing the distribution of the $\chi2$ statistic for good segments and bad segment (figure 6) one can decide to increase the $\chi2$ threshold to improve the classification errors. Locating the threshold at the intercepting point of the graphics the type I error decreases to 10,42% and type II error do not increase very much (11,4%). Assuming a type II error value of 15% it is possible to decrease the type I up to roughly the half part of the original one (figure 7).

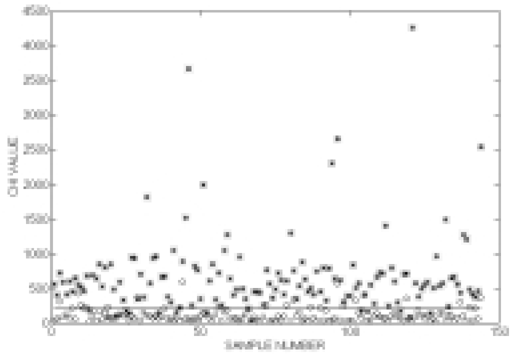


Fig. 5. Testing results

—	Critical Chi value
*	Chi value for bad segments
o	Chi value for good segments

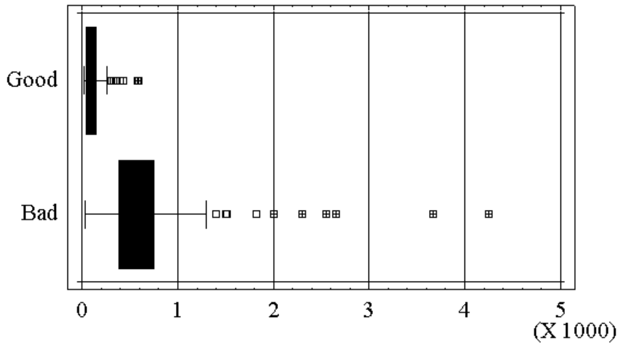


Fig. 6. Box and Whisker plot of $\chi2$ statistic.

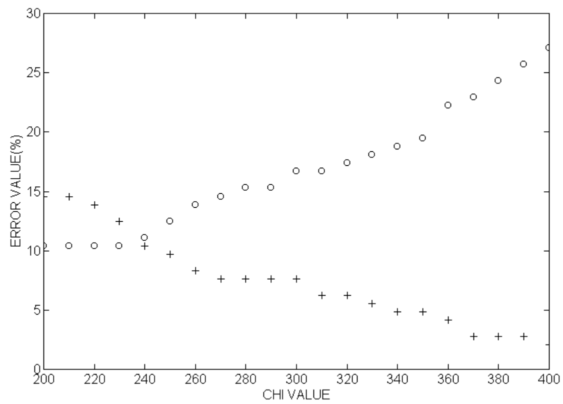


Fig. 7. Errors trend

+	Type I Error
o	Type II Error

The result is a desired improvement of the speed and quality of the inspection process compared to the current one carried out by human inspectors as figure 8 shows. Although the type I error does not have an important reduction the type II error does; and most of all there is a considerable increment of the inspection speed with an additional advantage of objectivity during the classification.

Actual prototype performance qualities include the inspection of up to ten orange segments by second, which makes it compliant with on-line requirements.

	Human Inspection	Automated Inspection
Type I Error	18%	14,6
Type II Error	30%	10,4%
Speed (VGA system)	600 ms/segment	64 ms/segment
Speed (Matrox Pulsar)	600 ms/segment	42 ms/segment

Fig. 8. Human inspection vs Automated Inspection.

Classification accuracy reaches a 10.4% producer's risk (good segments classified as bad segments) and around 14.6% customer's risk (bad segments classified as good ones). These results improve about 20% average classification score reached by manual inspection.

The AVI system will help to introduce a new high quality for this product not reachable by human inspection (extra fancy, containing less than 5% broken segments). As it is the think of preserved fruit/vegetable producers, this is the action line which will make the Spanish industry capable to face low prices coming from direct competitors in Asia and North of Africa. Once more, competitive advantage comes from higher quality rather than from lower prices for manpower.

8. ACKNOWLEDGEMENTS

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